HDL-TL-90-6, September 1990

Upgrade of Harry Diamond Laboratories Scale Model Facility:

II.—A Biconical/Dipole Antenna for Scale Modeling with a Self-Contained Repetitive Pulse Source

by

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Abstract

Harry Diamond Laboratories is currently upgrading its facility for electromagnetic scale modeling. This upgrade will consist of new pulse radiation sources, transducers, data couplers, instrumentation, and software. Each of these will be covered in a separate technical information letter, as the items come on line. The first letter in this series reports on the development of the pulse source, *A 2-kV Repetitive Pulse Source with a 100-ps Risetime.* This second letter reports on the development of an antenna that will provide horizontally polarized, repetitively pulsed fields to illuminate the models. The antenna, in the form of a bicone fed dipole, is a self-contained device in that the repetitive pulse source, discussed in the first technical letter, is housed within one of the cylinders which make up the dipole section. This letter also reports on how the antenna is controlled, operated, and deployed, as well as describing how the output field was found to have a risetime of approximately 150 ps with a level of 180 V/m at a radial distance of 3 m.

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Introduction

Harry Diamond Laboratories (HDL) conducts electromagnetic scale model experiments and tests to aid in the prediction of the responses of the external receptors of various Army systems to a simulated field which is representative, in scale, of that which results from a high-altitude nuclear explosion. This high-altitude electromagnetic pulse (HEMP) field simulation may be created by radiating a pulsed field from a biconical/dipole antenna. The resulting field induces currents on the receptors of the model under test, which are sensed and coupled to recording equipment housed in a shielded enclosure.

The upgrade for these efforts includes a biconical/dipole antenna that is completely self-contained.* That is, the antenna acts as the housing for a pulse source which consists of batteries, a high-voltage power supply, a high-voltage charge, delay lines, a shaping network, trigger circuitry, and a coaxially mounted mercury reed switch (MRS).[1] The antenna is operated remotely through a fiber-optic control system.

Figure 1 shows the new scale model antenna (SMA) in its ground position as it is kept when not in use or for disassembly. Electromagnetically, it is a 21-ft dipole, fed at its apex by a biconical section and terminated by rf absorbent material. The biconical section launches the leading edge of the applied pulse while the dipole section radiates

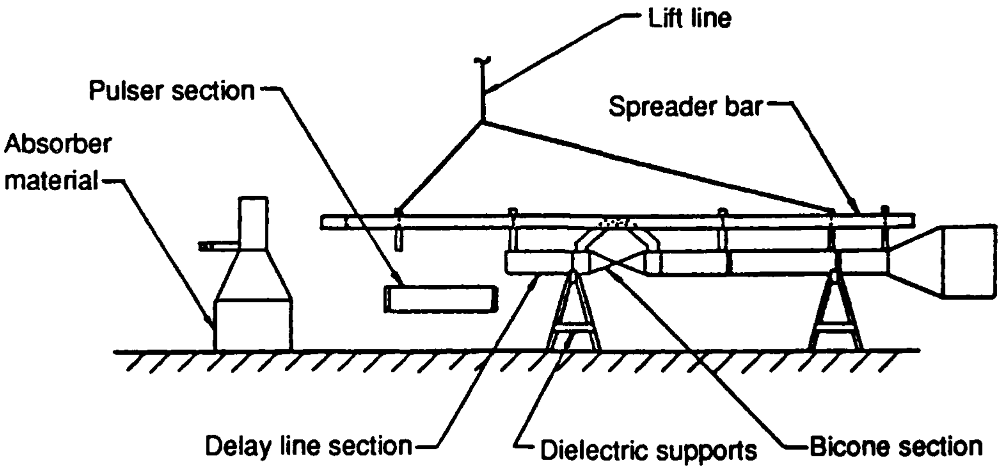

Figure 1. Pulser/antenna assembly.

[1]*Upgrade of Harry Diamond Laboratories Scale Model Facility: I. A 2-kV Repetitive Pulse Source with a 100-ps Risetime, Harry Diamond Laboratories, HDL-TL-90-5, July 1990.*
**The antenna was designed and fabricated by SOL Telecommunications Systems, Inc., under the direction of HDL.*

the late time pulse. For HEMP applications, the radiated pulse approximates a double exponential, with a risetime on the order of 150 ps and a decay time of approximately 20 ns. The rf absorbent material tends to minimize reflections from the ends of the dipole. The bicone half-angle is 12.5 deg, yielding an impedance of 270 ohms, and the dipole section is constructed from 6-in. aluminum tubes. One side of the dipole is merely empty tubing, while the other houses the electronic system which provides the pulse source to the bicones.

Pulse Source

Figure 2 is a simplified diagram which shows the SMA pulse source which is housed in one of the 4-ft sections of the dipole. This section is removable as a unit from the SMA and will function independently as a single-shot or repetitive pulse source, into 50 ohms. The SMA was modularly designed for ease of component replacement, and, in fact, a second identical pulser, housed within the same size tube, was constructed to act as a spare or as a pulse source for separate experimentation.

Control

As seen in figure 2, the pulser is controlled remotely via 50 m of fiber-optic cable. This control provides for turning on the high-voltage

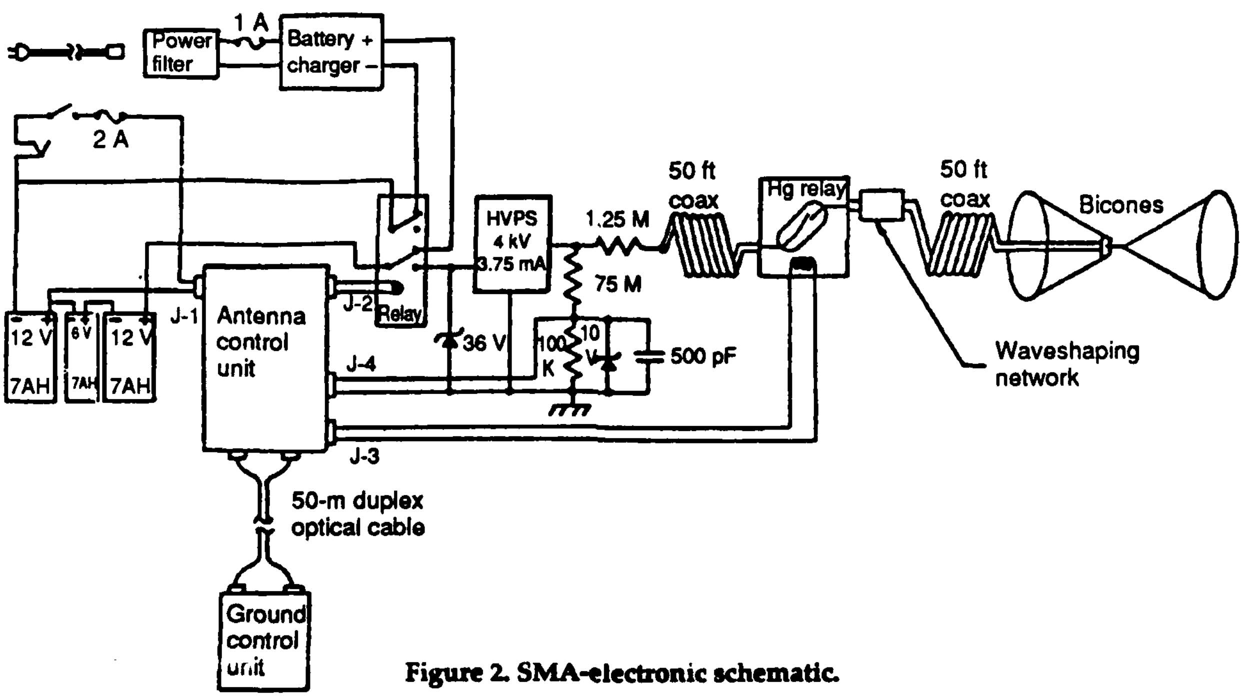

Figure 2. SMA-electronic schematic.

power supply, operating the SMA in the repetitive or single shot mode, changing the repetition rate, and monitoring the on-board high voltage and the battery level of the ground control units. The high-voltage ON/OFF feature is useful in that the SMA may be deployed to an elevated position above a model, ready for use, but drawing minimal current (~100 mA) from the on-board batteries while the high voltage is off. There is also an on-board primary power ON/OFF switch and a safety switch, as seen in the upper left of figure 2. These switches completely disable the pulser by turning off the antenna control unit. The safety switch is operated by a cable which plugs into the pulser section and the other side of the antenna. When in use, this cable prevents any difference of electrical potential between the two sides of the SMA.

The on-board batteries are sealed lead acid cells which can be charged through an rf filtered plug on the side of the pulser section, using a standard 115-V ac three-wire power cable. Lowering the SMA to a resting position is not necessary for achieving battery charging. The ground control unit, housed in a small shielded box (6 by 4 by 9 in.), is also battery operated for portability, and has its own charger. The SMA can be operated for 2 working days without recharging the on-board batteries.

Operationally, the SMA is a simple high-voltage charge line discharged very rapidly through an MRS into the bicone/dipole.

Specifications

The specifications for the SMA are as follows:

Parameter	Specification
Pulser (Electrical)	
Charge voltage	4000 V
Output impedance	50 ohms
Risetime	≤ 120 ps (10 to 90%)
Pulsewidth	77 ns
Repetition rate	60 to 120 pps
Energy per pulse	~11 mJ
Primary power (pulser)	7-A-hr battery
Primary power (remote control)	1.8-A-hr battery
Pulser (Mechanical)	
Dimensions	6 in. diam by 4 ft length (section)
Weight	35 lb

Antenna (Electrical)	
Bicone impedance	270 ohms
Electrical half-length	12 ns
Nominal field strength	>100 V/m at 3 m
Antenna (Mechanical)	
Dimensions	6 in. diam by 24 ft length
Weight (with pulser and mechanical spreader bar)	182 lb

Operation

When the high voltage is ON, the 50-ft coaxial charge line is at the same electrical potential as the output of the high-voltage power supply. This supply level may be adjusted to less than 4000 V, but not remotely. To radiate a field, the antenna control unit commands the MRS to close by applying current to a coil that is an integral part of the coaxial housing in which the MRS resides. This current may be a single pulse for single-shot, or a repetitive train of current pulses for a repetitively pulsed field. In either mode, the coaxially configured output of the MRS rises to 2000 V with a 10- to 90-percent risetime on the order of 100 ps.

The MRS output into a 50-ohm load would be a square wave approximately 154 ns in duration. When the SMA is applied to HEMP model experiments, the radiated field shape must approximate a double-exponential shape. This shape is approximated by a simple RC differentiating shaping network. Figure 3 is a recording of the pulser output through the shaper network.

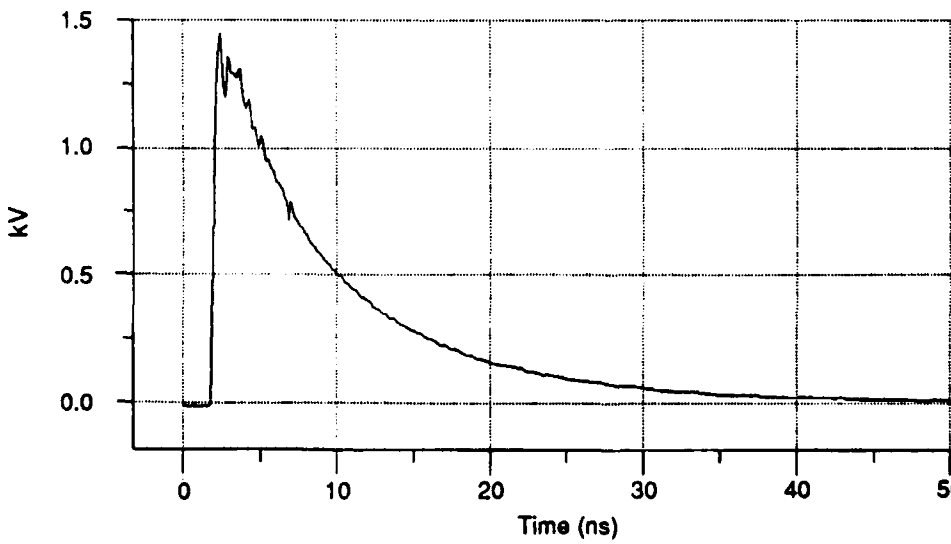

Figure 3. Pulser output.

The 270-ohm bicone impedance was dictated by physical limitations as to the diameter of the SMA. The 50-ft coaxial cable between the shaping network and the bicones is used as a time domain buffer. This is required because the impedance mismatch from the 50-ohm pulser output to the 270-ohm bicones causes a reflected pulse to be propagated back towards the pulse source, where it will be reflected once more toward the bicones. If the pulse source was physically close to the bicones, this reflection would be present in the radiated field. While this reflection from the bicones still occurs, the 50-ft line, with an electrical length of 77 ns, delays the re-reflected pulse from reaching the bicones for twice its electrical length, or ~154 ns. Previous experiments have shown that the electrical responses of a model, as caused by a scaled HEMP field, have taken place within a 100-ns window. That is, any currents induced in the model receptors by the field have decreased to zero before 100 ns have passed.

Calculated Electromagnetic Field

The following formula[2] may be used to calculate the electric field as radiated by a biconic antenna:

$$E_{pk}^{inc} = 60\ V_0 r Z_k\ ,$$

where

pk = peak,

inc = incident,

V_o = driving voltage,

r = radial distance, and

Z_k = bicone impedance.

While the SMA is a hybrid of a biconic and dipole radiator, the biconical section is of sufficient electrical length to radiate the peak of the applied pulse. Thus, this formula is applicable, provided that the calculation applies to a point on the equatorial plane of the bicones (perpendicular to bicone length at the bicone apex), with sufficient

[2] *J. Krause, **Antennas**, McGraw-Hill Book Co., NY (1950), p 221.*

height above the ground for the peak free field level to be attained before the ground reflected wave arrives.

Before this calculation may be made, V_o, the driving voltage, must be known. As seen in figure 3, the shaper output is approximately 1475 V, peak. If we ignore the loss in the coupling (buffer) cable, the driving voltage at the bicones will be approximately the value applied (V_a) plus that voltage reflected at the coaxial to bicone interface. The theoretical bicone impedance is 270 ohms, which was confirmed (approximately) by using time-domain reflectometry techniques. The reflection coefficient of the bicone may be found from

$$\rho = Z_k - Z_o / Z_k + Z_o \ ,$$

where

ρ = reflection coefficient,

Z_k = bicone impedance,

and

Z_o = coax impedance;

therefore,

$$\rho = 270 - 50/270 + 50,$$
$$= 0.6875,$$

and

$$V_o = \sim (V_a \cdot 1.6875) \ ,$$
$$= \sim (1475 \cdot 1.6875) \ ,$$
$$= \sim (2490 \text{ V}) \ .$$

Applying the formula for a range of 1.5 m, we find

$$E_{pk}^{inc} = 60 \cdot 2490/1.5 \cdot 270$$
$$= \sim 369 \text{ V/m} \ .$$

Measured Electromagnetic Field

Peak Field

The SMA field was measured using a magnetic (H) field sensor (MGL-7 by EG&G) and an electric (E) field sensor (HDL D-6). The peak values of the measured field expressed in volts per meter were 337 and 372, as projected to the 1.5 m range used in the calculation. The combined calculated and measured fields yield a value of approximately 180 V/m at the specified range of 3 m.

Field Rise Time

The measurement indicated that the risetimes of the H- and E-field sensors were 361 and 346 ps, respectively (10 to 90 percent). The risetime capability of the measurement systems composed of the sensor(s), cable, delay line, and time domain sampling oscilloscope was approximately 320 ps. Using the square root of the difference of the squares to estimate the risetime, we obtain

$$T_r = [(T_i)^2 - (T_s)^2]^{1/2} ,$$

where T_i = indicated risetime and T_s = system risetime.

The H-field recording yields 167 ps; the E-field, 132 ps, both 10 to 90 percent. These values indicate that the SMA has achieved its specified risetime of 150 ps.

Late Time

The recorded electric field is seen in figure 4. For this recording, the E-field sensor and the SMA were both 2.5 m above the ground, with the sensor on the center line of the SMA at a range of 1.4 m. The calculated arrival time of the field reflected from the ground is 12.6 ns. It appears in the waveform at 13.3 ns, which is within 6 percent of the calculated time.

For this relationship of antenna and sensor, the calculated arrival time for reflection from the ends of the SMA is 8.5 ns. No significant change is observed in the waveshape at this time. This may not be true when field measurements are performed off the center line of the SMA.

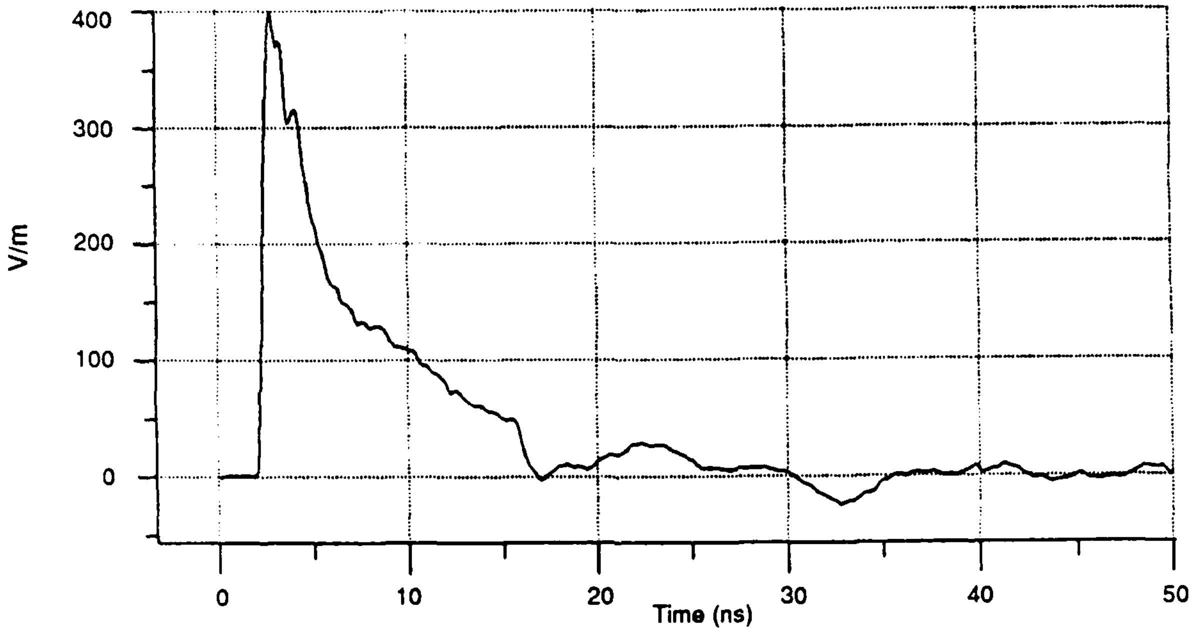

Figure 4. Radiated field.

Conclusions

The new SMA is a significant advancement for electromagnetic time-domain scale modeling. It has been provided with a new support structure and hydraulic winch system which allow the SMA to be quickly and easily positioned anywhere above the 60 by 80 ft scale model test bed. The support system includes a 40-ft fiberglass counter-weighted boom where the SMA may be mounted and rotated in a 20-ft radius to observe azimuthal changes in a model's response.

As with anything, there is always room for improvement. With the SMA, this means decreasing the risetime of the radiated field, which most likely can be done, and providing an advanced trigger from the pulser to the measurement instrumentation. This trigger is required only for electromagnetic field measurements, since it would significantly improve the measurement system risetime capability by eliminating the currently required trigger pick-off/delay line. HDL is investigating the use of an infrared (IR) or ultraviolet (UV) light trigger system between the SMA and the instrumentation.